REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE** Technical Paper	**3. DATES COVERED** *(From - To)*
4. TITLE AND SUBTITLE Please see attached		**5a. CONTRACT NUMBER** F04611-97-C-0079
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		**5d. PROJECT NUMBER** 4373
		5e. TASK NUMBER 00US
		5f. WORK UNIT NUMBER 346224
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Pratt & Whitney		**8. PERFORMING ORGANIZATION REPORT**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory (AFMC) AFRL/PRS 5 Pollux Drive Edwards AFB CA 93524-7048		**10. SPONSOR/MONITOR'S ACRONYM(S)**
		11. SPONSOR/MONITOR'S NUMBER(S) Please see attached

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

20030116 074

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Leilani Richardson
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	A		**19b. TELEPHONE NUMBER** *(include area code)* (661) 275-5015

MEMORANDUM FOR PRR (Contractor Publication)

FROM: PROI (TI) (STINFO) 08 Jun 2000

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-TP-2000-126**
Rodriguez, Jose (Pratt & Whitney), "Design and Test of a Radial Inflow Turbine for an Advance Liquid Hydrogen Turbopump"

AIAA Joint Propulsion Conference **(Statement A)**
(Huntsville, AL, 17-19 Jul 00) **(Submission Deadline: none given)**

1. This request has been reviewed by the Foreign Disclosure Office for: a.) appropriateness of distribution statement, b.) military/national critical technology, c.) export controls or distribution restrictions, d.) appropriateness for release to a foreign nation, and e.) technical sensitivity and/or economic sensitivity.
Comments:______________________________

Signature ______________________ Date ____________

2. This request has been reviewed by the Public Affairs Office for: a.) appropriateness for public release and/or b) possible higher headquarters review.
Comments: ______________________________

Signature ______________________ Date ____________

3. This request has been reviewed by the STINFO for: a.) changes if approved as amended, b.) appropriateness of distribution statement, c.) military/national critical technology, d.) economic sensitivity, e.) parallel review completed if required, and f.) format and completion of meeting clearance form if required
Comments:______________________________

Signature ______________________ Date ____________

4. This request has been reviewed by PR for: a.) technical accuracy, b.) appropriateness for audience, c.) appropriateness of distribution statement, d.) technical sensitivity and economic sensitivity, e.) military/ national critical technology, and f.) data rights and patentability
Comments:______________________________

APPROVED/APPROVED AS AMENDED/DISAPPROVED

____
LAWRENCE P. QUINN DATE
Technical Advisor
Rocket Propulsion Division

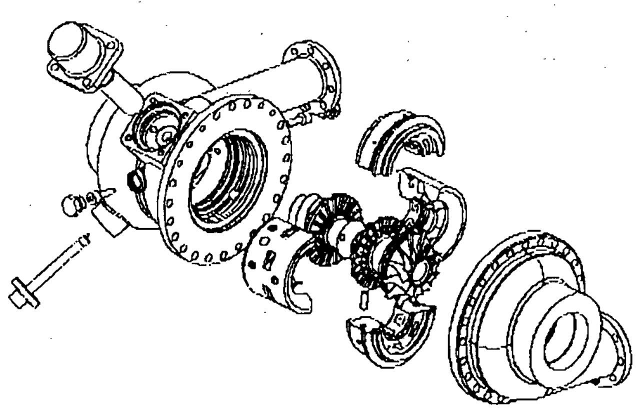
AIAA 2000-0158

Design and Test of a Radial Inflow Turbine for an Advance Liquid Hydrogen Turbopump

J. L. Rodriguez

Pratt & Whitney
West Palm Beach, Fla.

NOTES: Figure Capitalization



36th AIAA/ASME/SAE/ASEE Joint Propulsion
Conference and Exhibit
17-19 July 2000
Huntsville, Alabama

Dist. A: Approved for public release; distribution unlimited.

ABSTRACT

Pratt & Whitney has developed a high performance Radial Inflow Turbine (RIT) to power the Advanced Liquid Hydrogen Turbopump (ALH) for the Upper Stage Demonstrator Engine. The design is based on Pratt & Whitney (PW) developed RIT methodology that reduces axial length and tip diameter compared to state-of-the-art RIT's, while maintaining or exceeding existing performance levels. The full power speed is very high delivering required power to the pump. Included are the design characteristics and preliminary test results at low speed.

INTRODUCTION

The Advanced Liquid Hydrogen Rocket Turbopump (ALH) for the Upper Stage Development Engine requires a very high speed (Ref.1). At these speeds a RIT is determined to meet overall design requirements. The design is based on PW developed methodology that produces reduced axial length and tip diameter compared to state-of-the-art RIT's, while maintaining or exceeding existing performance levels. The reduced diameter is used for increased speed capability while maintaining structural integrity.

For reduced part count, the inlet volute design produces the desired inlet swirl with minimum hardware complexity. The inlet volute is more efficient, lighter, and reduces side loads on the rotor during transient and steady state operation compared to a traditional inlet manifold. Extensive Computational Fluid Dynamics (CFD) analysis is used to ensure uniform pressure and angle distributions at the rotor inlet as well as to minimize volute-rotor interaction effects.

The compact rotor has highly loaded unshrouded blades designed for operation over a wide power range without performance penalty. Exit guide vanes are used to minimize the swirl at the rotor exit and reduce the losses in the exit duct.

TURBOPUMP DESCRIPTION

The Advanced Liquid Hydrogen Turbopump will be used in a medium thrust Upper Stage Expander Cycle Engine being developed by Pratt & Whitney Liquid Space Propulsion under contract for the United States Air Force Research Laboratory (AFRL) to support the Integrated High Payoff Rocket Technology (IHPRPT) INITIATIVE ~~program.~~ The Advanced Liquid Hydrogen Turbopump is designed to provide improved system thrust to weight, decreased hardware/support costs, and increased reliability. These benefits will be accomplished and demonstrated through design, development, and test of this high speed, high efficiency, hydrogen turbopump capable of supplying the engine required liquid hydrogen at high pressure. Figure 1 shows the turbopump.

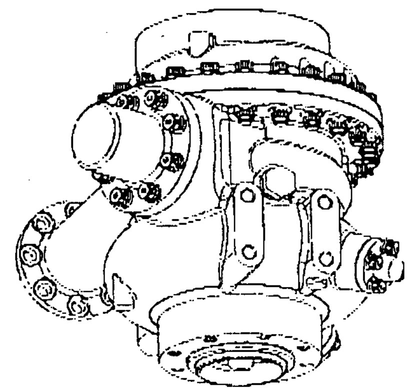


Figure 1. Advanced Liquid Hydrogen Turbopump

TURBINE DESIGN

The ALH turbine system includes traditional turbine subcomponents: an inlet manifold, rotor and discharge manifold. Figure 2 shows the geometric definition of the overall system.

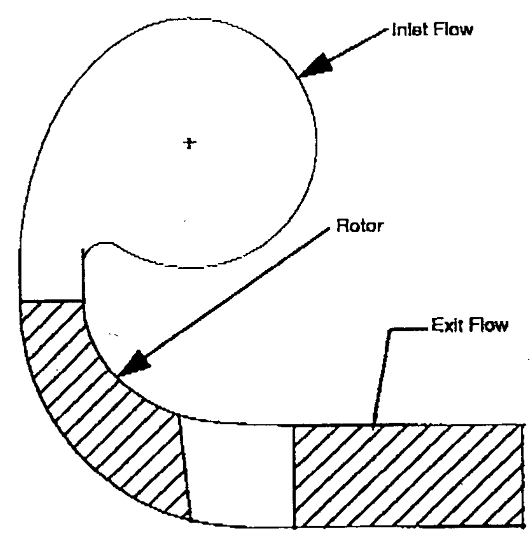


Figure 2. ALH Turbopump Turbine System

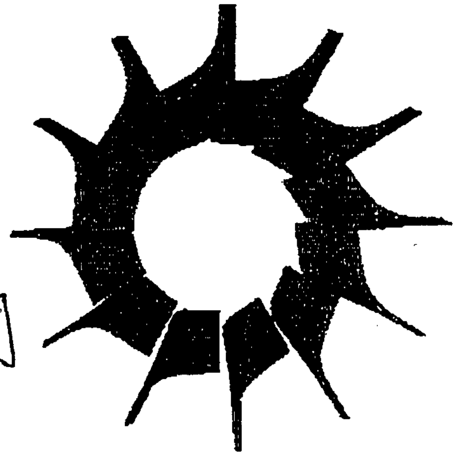


Figure 7. Compact Radial Turbine Geometry

DIFF PIC.

Rotor Design

The ALH rotor is shown in Figure 7. An important design feature of the rotor is the capability for stable operation at partial power. CFD analysis of the rotor shows that the flow is well behaved at both full and partial power.

Figure 8 shows flowpath velocity vectors at suction side, mid channel and pressure side at full power. Figure 9 shows midspan leading edge velocity vectors and mid-channel at design point. Figure 10 shows midspan leading edge and mid-channel velocity vectors at 50% power.

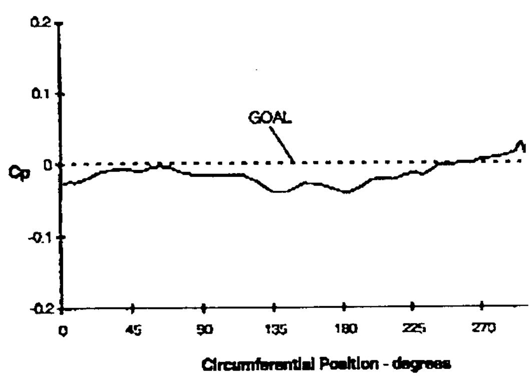


Figure 6. Turbine Inlet Manifold Circumferential Pressure Distribution at 100% power

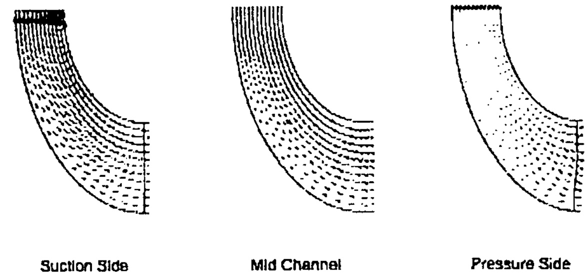


Figure 8. Radial Turbine Flowpath Velocity Vectors at 100% power

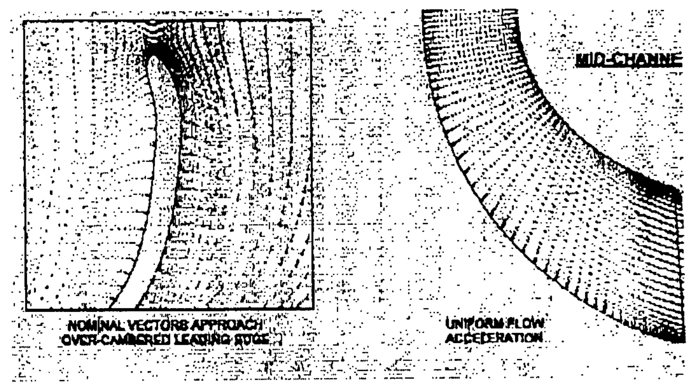


Figure 9. Radial Turbine Velocity Vectors at 100% power

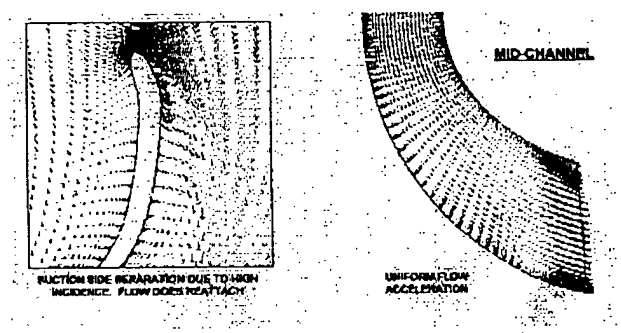


Figure 10. Radial Turbine Velocity Vectors at 50% power

Figure 11 shows the spanwise distribution of relative Mach number and gas angle obtained from the CFD model. Figure 12 shows the relative Mach number at the midspan section for both the design point and 50% power. The flow is well behaved at all conditions, leading to desired turbine performance levels. Figure 13 shows Mach contours in the mid-channel.

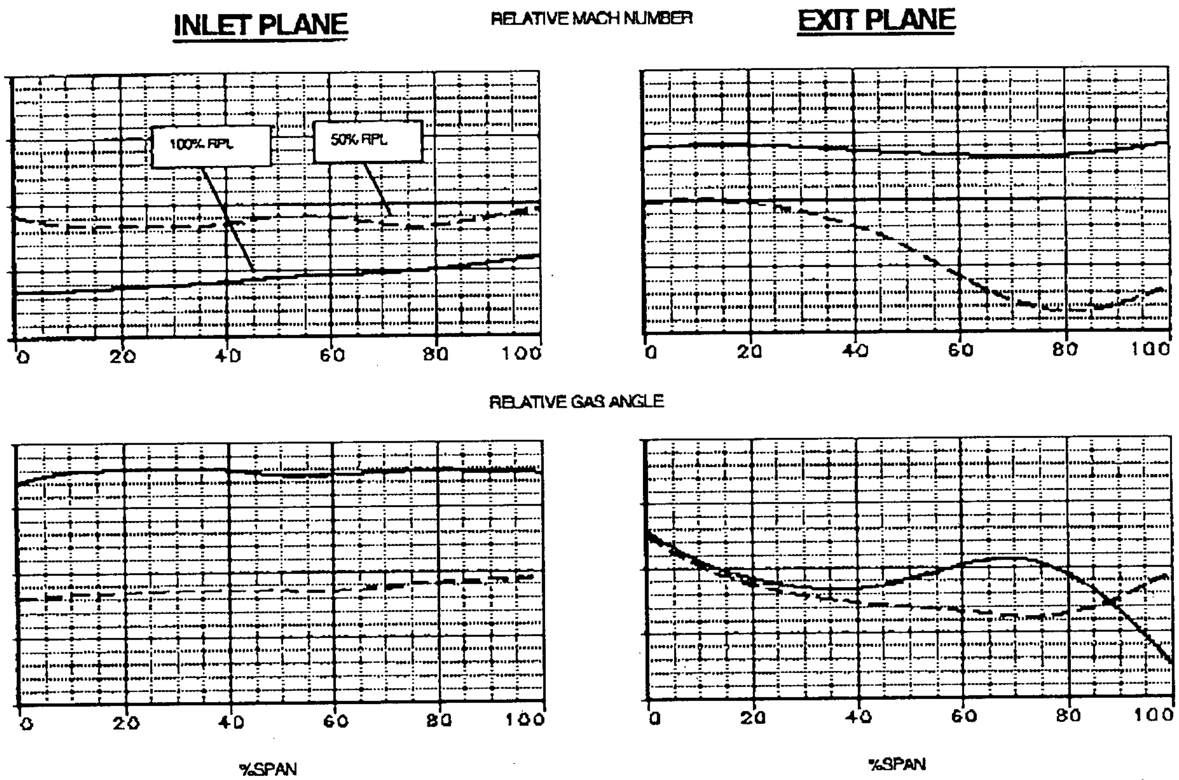


Figure 11. Turbine Spanwise Distribution of relative Mach number and gas angle

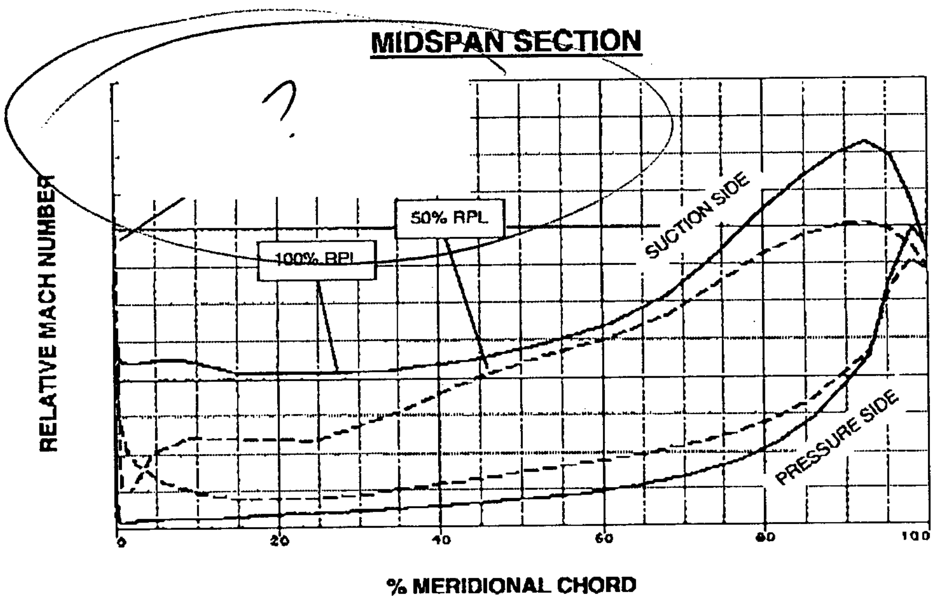
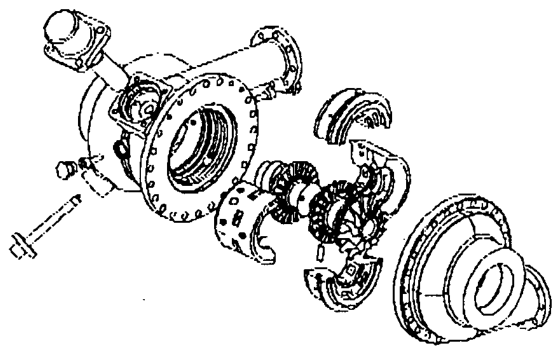


Figure 12. Relative Mach number at Midspan for 100% and 50% power



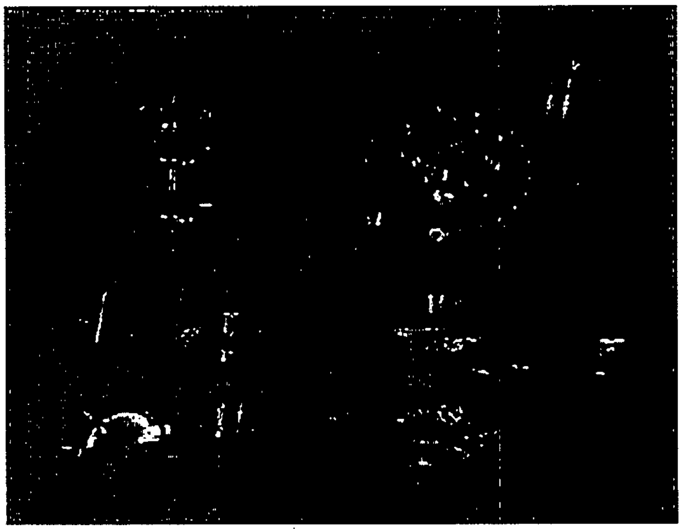


Figure 16. Low parts count simplifies assembly

↓ is original copy better?

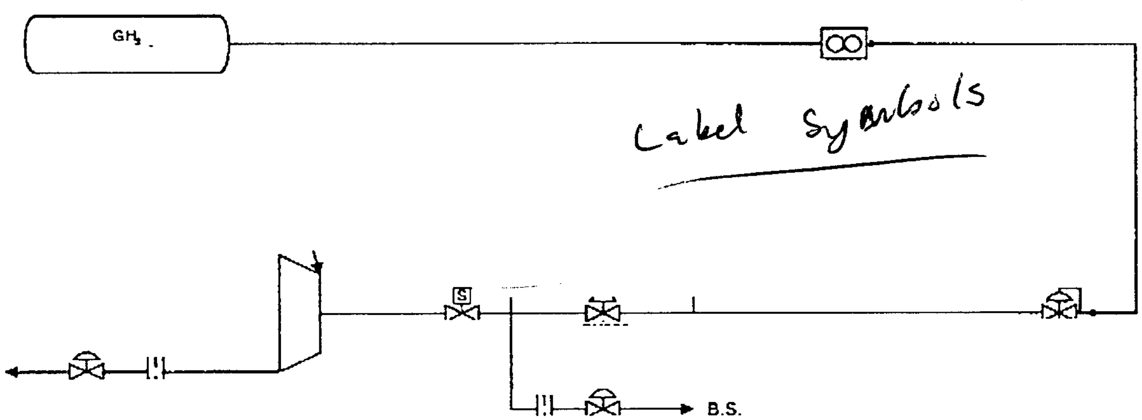
EXPERIMENTAL PROCEDURE

The design approach has been to promote simplicity via low parts count. Low parts count has proven to improve maintainability, cost, and reliability, and reduce weight. Lower parts count also minimizes the dimensional tolerance stack-ups that are critical to turbopump performance. To minimize parts count the turbopump design uses a single piece rotor, two cast housings, and two split bearings for a total of only ~~8~~ 7 primary parts (Figure 16). The increased speed of the ALH allows the pump and turbine diameters to be reduced with a small shaft length (Ref.1).

Test Facility

The turbine aerodynamics test is part of the overall turbopump system test. The test facility requirements are (Ref.1):

- Facility mechanical system to accommodate all pump and turbine flows, pressures and temperatures.
- Data recording capability to record all facility and test article parameters at very high ~~scans per second~~. Sample rates.
- Control system to provide control of the pump discharge, turbine exit, and inlet valves.



Label symbols

Figure 17. GH2 Supply/Discharge System

figure 17 should be referenced in text ~~displayed~~ before it is shown

Hydrogen is supplied from a large high-pressure tank (Figure 17). This facility allows run times to reach the several second range without a decrease of the control system stability. The GH2 supply safety systems includes a rupture disk and a relief valve. Downstream of the control valves, a fast acting, pneumatic valve was used as the rig safety shutoff valve. Discharged gas is routed to a burn stack.

Test Results

The 35% point steady state test results at low RPM indicate that the turbine produces expected ~~HP~~ horse power and torque. Figure 18, compares the design and corrected experimental efficiency for the 35% point and shows the target efficiency, not test results, for the 50% and 100% design points. The performance of the turbine agrees well with design predictions at the 35% point. Figure 19 shows that the flow parameter falls within the expected range in the turbine design map.

The degree of thermal equilibrium obtained depends on the temperature distribution on the system. The temperature corrected efficiency and velocity ratio are 55% and 0.42 at 35% RPL.

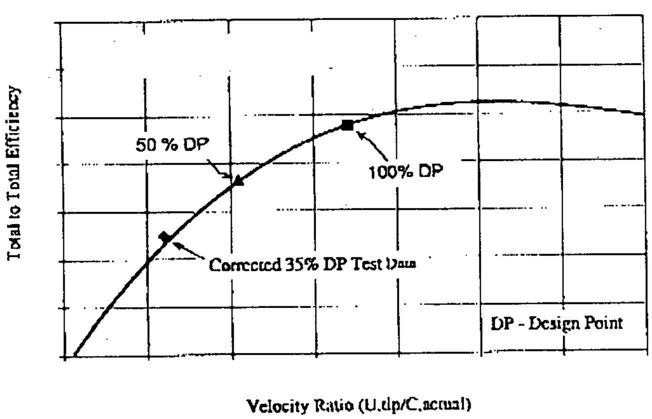


Figure 18. Total - Total Flange to Flange Efficiency

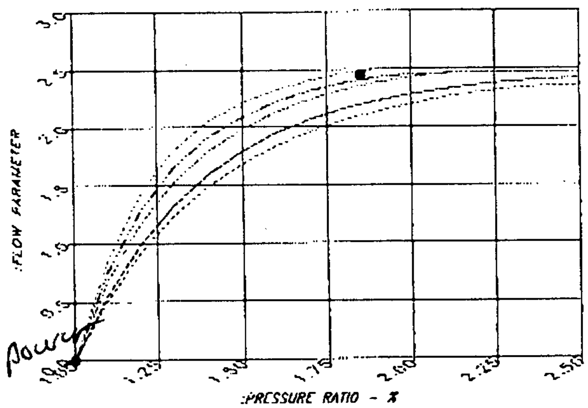


Figure 19. Turbine Flow Parameter vs. Pressure Ratio

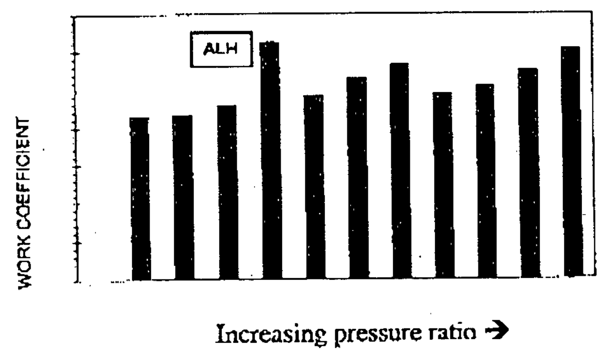


Figure 20. Work Coefficient for the ALH Turbine at 100% power

CONCLUSION

The turbine design is state-of-the-art. Figure 20 shows the work coefficient at 100% RPL. At this pressure ratio, the performance of the ALH is superior to other radial inflow turbines considered. The CFD analysis shows that 2:1 throttling is achievable and that the flow at both 50% and 100% rated power is stable and well behaved. The preliminary tests indicate that performance is as expected. As the test proceeds, further data will be reported.

ACKNOWLEDGEMENTS

The data presented in this paper was generated with the help and support of a large number of members of the PW/USAF ALH team, the author wishes to acknowledge and thank the team members. In particular ~~we~~ thank A. J. Fredmonski, X. Montesdeoca, F. Huber and P. D. Johnson. ~~The following~~ THIS work was supported by USAF/AFRL under contract F04611-95-C-~~0123~~ 0029. ~~We~~ thank Eric Schmidt, program manager, for ASSISTING IN ~~allowing~~ the publication of this paper. Special thanks to William Watkins for his help ~~is sanitizing~~ IN PREPARING the paper ~~to meet ITAR requirements.~~

REFERENCES

1. Crease, R., Grabowski, K., Kincaid, J., Friant, J., Rodriguez, G., Gualtieri, L., Chapman, T., Haykin, "Testing of an Advance Liquid Hydrogen Turbopump", AIAA 2000-3679, 36th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, July 17-19, 2000. ?